Low temperature ferromagnetism in the new diluted magnetic semiconductor p-$Bi_{2-x}Fe_xTe_3$

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Abstract

Single crystals of the new diluted magnetic semiconductor of p-$Bi_{2-x}Fe_xTe_3$ ($0 \leq x \leq 0.08$) and n-$Bi_{2-x}Fe_xSe_3$ ($0 \leq x \leq 0.06$) have been synthesized. The ferromagnetic phase was found at a temperature T_c which increases with Fe content x up to $T_c = 12$K for $x = 0.08$ in p-$Bi_{2-x}Fe_xTe_3$. The easy-axis for magnetization is parallel to the C_3 crystallographic axis. In n-type samples $Bi_{2-x}Fe_xSe_3$ ferromagnetic transition was not found down to 2 K. The de Haas-van Alphen effect was observed in p-$Bi_{2-x}Fe_xTe_3$. The Shubnikov - de Haas (SdH) effect was investigated in both types of samples. Frequency of oscillation decreases with Fe doping in p-$Bi_{2-x}Fe_xTe_3$ and increases in n-$Bi_{2-x}Fe_xSe_3$. Thus Fe atoms exhibit donor properties.

Key words: diluted magnetic semiconductors; ferromagnetism

1. Introduction

Recently, the discovery of hole-mediated ferromagnetic order in diluted magnetic semiconductors (DMS) (In,Mn)As was made [1]. Then ferromagnetic transitions were found in DMS (Ga,Mn)As [2,3]. We have synthesized single crystals of the new diluted magnetic semiconductor of p-$Bi_{2-x}Fe_xTe_3$ ($0 \leq x \leq 0.08$) and n-$Bi_{2-x}Fe_xTe_3$ ($0 \leq x \leq 0.06$) [4].

2. Experimental

For measurements of magnetic susceptibility and magnetization in the temperature interval 2-300 K in magnetic field up to $B = 7$ T SQUID magnetometer "MPMS-XL7L" Quantum Design Co. Ltd. was used. The SdH effect was investigated in pulse magnetic fields up to 35 T at $T = 4.2$K.

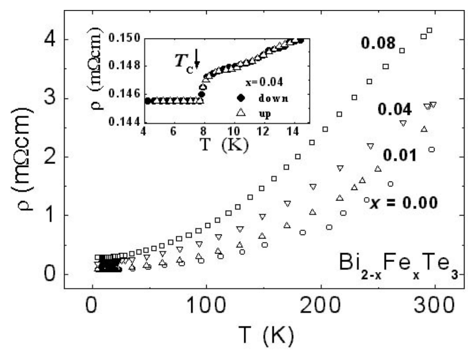

Fig. 1. Temperature dependence of resistivity for p-$Bi_{2-x}Fe_xTe_3$.

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3. Results and Discussion

From the DC transport measurements, it was found that the resistivity of all samples decreases with decreasing temperature. The resistivity increases continuously in p-$Bi_{2-x}Fe_xTe_3$ (Fig. 1) or decreases in n-$Bi_{2-x}Fe_xSe_3$ (Fig. 2) as the Fe doping was increased.

The magnetic susceptibility χ of single crystals Bi_2Te_3 is diamagnetic and temperature independent with the value of $\chi_{C3} = -0.45 \times 10^{-6}$ emu/g in C_3 direction (perpendicular to the layers) and $\chi_{C2} = -0.33 \times 10^{-6}$ emu/g in C_2 direction (parallel to the layers). The magnetic susceptibility of n-Bi_2Se_3 over the temperature range of 2 to 300 K is diamagnetic and temperature independent with the value of $\chi_{C3} = \chi_{C2} = -0.3 \times 10^{-6}$ emu/g, *i.e.* isotropic.

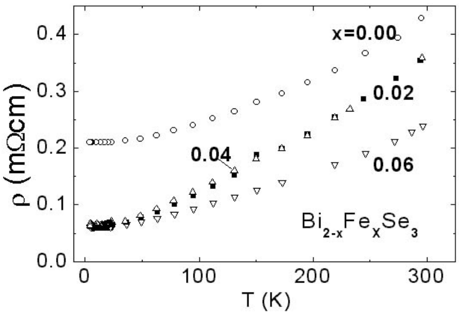

Fig. 2. Temperature dependence of resistivity for n-$Bi_{2-x}Fe_xSe_3$.

Due to magnetic impurity in doped sample the susceptibility χ depends on temperature and the absolute value of χ gradually increases with iron content x. $Bi_{2-x}Fe_xSe_3$ is a paramagnetic. Ferromagnetic transition was observed in Fe-doped $Bi_{2-x}Fe_xTe_3$ with the maximal temperature $T_c = 12$ K ($x = 0.08$). Fig. 3, as an example, shows the magnetization data for $Bi_{1.92}Fe_{0.08}Te_3$ and $Bi_{1.96}Fe_{0.04}Se_3$. The width of the hysteresis loop in $Bi_{2-x}Fe_xTe_3$ depends not only on Fe content x but also on the orientation of magnetic field.

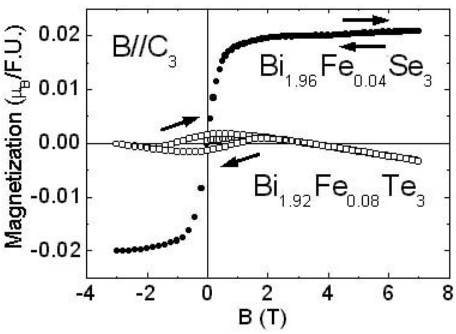

Fig. 3. Magnetization on magnetic field for $Bi_{1.92}Fe_{0.08}Te_3$ and $Bi_{1.96}Fe_{0.04}Se_3$.

The easy axis of magnetization is parallel to the C_3 axis. We also observed the anomalous Hall effect (Fig. 4) and jump of the resistivity at $T = T_c$ due to switching off the spin-flip scattering of carriers (see insert in Fig. 1).

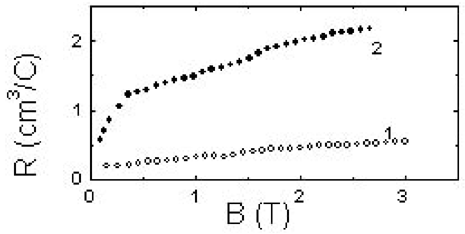

Fig. 4. Magnetic field dependence of the Hall coefficient R_H for Bi_2Te_3 (1) and $Bi_{1.92}Fe_{0.08}Te_3$ (2).

In $Bi_{1-x}Fe_xTe_3$ samples the de Haas-van Alphen effect was observed. We investigated SdH effect in magnetic fields up to 35 T in the both type structures. Using the SdH frequency F, the carrier concentrations and Fermi-energy were calculated (Table 1). The method of calculation is described in [4, 5]. As it's seen in table 1 Fe atoms exhibit donor properties.

Thus hole-mediated ferromagnetism was found in p-$Bi_{2-x}Fe_xTe_3$. The RKKY interaction is most likely responsible for the appearance of ferromagnetism in p-$Bi_{2-x}Fe_xTe_3$. We did not find ferromagnetism in $Bi_{2-x}Fe_xSe_3$ from room temperature down to 2 K.

$Bi_{2-x}Fe_xTe_3$				$Bi_{2-x}Fe_xSe_3$			
x	F (T)	p (10^{18} cm^{-3})	E_F (meV)	x	F (T)	n (10^{18} cm^{-3})	E_F (meV)
0	26	7.5	37.8	0	150	1.9	145
0.01	23	6.3	33.5	0.02	162	2.1	156
0.04	18.1	4.4	26.4	0.04	218	3.7	208
0.08	11.5	2.2	16.7	0.06	242	5.1	233

Table 1
Dependence of the SdH oscillation frequency F, hole (p) or electron (n) concentration and Fermi energy E_F on doping level in $Bi_{2-x}Fe_xTe_3$ and $Bi_{2-x}Fe_xSe_3$. The loaded (for single crystal growth) value of x is shown.

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